Senior Thesis

MINERAL COMPONENT ANALYSIS OF THE EGERSUND DIKE SYSTEM IN SOUTHERN NORWAY

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ABSTRACT

Recently CFBs or Continental Flood Basalts have become an area of interest for researchers of petrology. CFB eruption is believed to be involved with many of the earth's vital processes such as continental breakup, extinction events and crustal accretion. Athough it is not formally known as a major CFB province, the Egersund Dikes in SW Norway provide a fresh and accessible sample of these types of basalts. There has been speculation as to just how CFBs evolve in the mantle, specifically whether or not subduction is involved. A detailed study of the chemical composition of plagioclase feldspar, olivine and pyroxene was performed for this study. Relative percentages of each mineral in terms of its end members was obtained and plotted onto several phase diagrams. Electron microprobe analyses of pyroxene grains were used in an attempt to determine whether the samples from the Egersund dikes were calc-alkaline or tholeiitic in nature. An FE-enrichment trend normally diagnostic of tholeiites was not detected in the graphs, however a plot of SiO_2 vs. FeO/MgO revealed all of the samples to be tholeiitic. It was determined from lack of experimental data that the dikes are in fact tholeiitic and that subduction was not a factor in the genesis of these dikes.

INTRODUCTION

Continental Flood Basalts (CFBs) are generally regarded as rapidly erupting basalts with enormous quantities of magma brought to the surface in a very short time period, geologically speaking. Interpreting CFB volcanism is important because it appears to have a major effect on our Earth's history. Large eruptions of CFBs may be related to crustal accretion, extinction events, the breakup of continental masses and other important geological processes. These factors have aroused new interest in the study of CFBs which will undoubtedly solve many geologic mysteries in the future.

The exact mechanism responsible for bringing Continental Flood Basalts to the surface is not explicitly known. A popular theory is that CFBs erupt through rifts located above thermal anomalies in the mantle (NSF proposal, 1991). As the lithosphere is pulled apart it becomes stretched and thinned. The pressure of the underlying asthenosphere is subsequently lowered causing it to melt. Pressure and temperature are important factors in determining the chemical composition of the magma and likewise, the chemical composition may reveal clues to conditions of formation. It is also believed that rifting may be caused by nearby thermal plumes which are the driving force of convection in the mantle. Complicating matters somewhat is the role of subduction in CFB petrogenesis. Some research has indicated that the chemical character of some CFB's are influenced by crust that had been subducted into the mantle source region (Hergt et. al., 1991). Moreover, there is speculation as to whether or not subducton of crustal sediment catalyzes the melting process. If subduction has occurred, then the dikes would be expected to contain rock suites that are calc-alkaline in composition and not tholeiitic.

There is significant evidence that eruption of CFBs is a major form of crustal accretion. Basalts erupted at the Deccan Plateau in western India now cover more that 200,000 square miles and covered probably twice as much previous to erosion. The Columbia River Province has been estimated to contain 100,000 - 200,000 cubic miles of basalt. These are but two examples of the enormity of volummes produced by CFB eruptions. Research has also suggested that CFB volcanism is associated with continental breakup. The evolution of Gondwanaland and the opening of the North Atlantic Ocean are two primary examples (White and Mckenzie, 1989).

The purpose of this paper is to consider certain mineral components (particularly plagioclase feldspar, pyroxene and olivine) of CFB samples taken from the Egersund dike complex in southern Norway. In doing this constraints may or may not be placed on their evolution and may be related to models concerning the evolution of other CFBs. Specifically, an attempt will be made to show what role subduction may have played if any, in the formation of the dikes by determining whether the dikes are calc-alkaline or tholeiitic. This determination will be made by considering two factors. The first is that tholeiitic basalts should display an Fe-enrichment trend amongst the pyroxenes. The second is that tholeiitic basalts should plot in the tholeiite field in a compositional graph of % SiO_2 vs. FeO/MgO (in wt. %).

GEOLOGIC BACKGROUND OF THE DIKES

The samples analyzed in this study were taken from the Egersund dikes, located in southwestern Norway. There are fifteen dikes in the complex ranging from 0.3 to 30 m in width and traceable for distances of up to 60 km (NSF proposal). They were emplaced as part of a swarm in a NW trending fault system, cutting across late precambrian country rock. Rb/Sr and Sm/Nd isotope dating has determined an age of 630-650 m.y. for the dikes. Interestingly enough, this age seems to be concordant with the time of the opening of the Iapetus Ocean. It is possible that these dikes may have been associated with the rifting leading to the opening of Iapetus. Paleomagnetic data obtained by Poorter (1972) supplies further evidence for dike emplacement during continental breakup. Although huge volummes of basalt were brought to the surface, none of it remains as it has been eroded away.

Many of the complications that arise when studying CFB provinces are related to the fact that it is difficult to find good data. Often times, these provinces are very old and as a result, significant alteration has occurred due to chemical weathering. This makes chemical analysis of samples collected from an area such as this virtually impossible. The Egersund dikes, which are relatively fresh as well as accessible, provide an exception to this general rule. The field relations are well known also, enhancing their compatibility with current research methods.

METHODS

In this study five samples collected from the Egersund dikes were used. They are numbered 105-1, 106-2, 118-1, FL-2A, and ME-186. All of the basalt samples had thin sections cut from them previous to this report. Chemical analysis using the electron microprobe was performed on the thin sections derived from the above samples. During the microprobe analysis, selected mineral grains from each of the five thin sections were identified and then analyzed individually. Only analyses executed on plagioclase feldspar, pyroxene, and olivine mineral grains are considered here. In some cases, more than one chemical analysis was run on a mineral grain if the grain was deemed to be large or a well defined phenocryst. Grains of this nature often times required an analysis run near the center (core) and one taken near the edge (rim) for the purpose of revealing any chemical zoning which may have occurred during the crystallization process. Every manually chosen data point was analyzed by the microprobe and displayed as chemical weight percentages in terms of oxides. Analyses whose calculated error of the weight percent sum exceeded 1% were discarded from this study as a general rule.

The next step was to calculate the relative chemical composition of the mineral grains in terms of their end members . for plagioclase, the end members are orhtoclase ($KAlSi_3O_8$), albite ($NaAlSi_3O_8$), and anorthite ($CaAl_2Si_2O_8$); for pyroxene, orthoferrosilite ($FeSiO_3$), enstatite ($MgSiO_3$), and wollastanite

($CaSiO_3$); for olivine, forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). Once the data was calculated in terms of its end members, it was plotted onto phase diagrams. The plagioclase data was plotted onto a triangle representing the system orthoclase-albite-anorhtite (OR-AB-AN). Both pyroxene and olivine data was plotted onto a pyroxene quadrilateral representing the system orthoferrosilite-enstatite-diopside ($CaMgSi_2O_6$)-hedenbergite ($CaFeSi_2O_6$) (represented by Fe, En, Di, Hd).

Finally, a graph of % SiO_2 vs. FeO/MgO was constructed in order to reveal whether the dikes are calc-alkaline or tholeiitic and whether or not subduction may have occurred.

DISCUSSION OF DATA

This first part of the data analysis will observe the chemical composition of plagioclase feldspars in the system OR-AB-AN. The ternary diagrams of all five samples are located in the **appendix.** Samples 105-1 and 106-2 consist of groundmass samples only as there were no significant phenocrysts present in either of the thin sections. Samples 118-1, FL-2A, and ME-186 do contain phenocrysts however, most of which have had analysis run at the core and rim. The appropriate symbols can be found in the legend accompanying each graph.

The sample labeled 105-1 shows a somewhat homogeneous chemistry of the feldspars. All of the grains tested plot within An_{30-50} (30-50% anorthite) and contain less than Or_{10} (10% Orhtoclase). The name given to this compositional field in which all of the 105-1 feldspars lie is called andesine.

Sample no. 106-2 shows similar chemical composition to 105-1 for the most part. The majority of the grains tested in this sample were also andesine in composition. Four of the plotted outside of the andesine cluster revealing another type of felspar in this sample. Their compostions are relatively enriched in K (Or_{30-40}) and contain very little Ca (An_{0-10}). The name given to these feldspars is sanidine. These sanidines were probably analyzed within the country rock band located on this thin section.

As mentioned above, samples 118-1, FL-2A, and ME-186 all contain core and rim, as well as groundmass grains that were analyzed. In 118-1, nearly all of the data lies within An_{40-70} and less than Or_{10}(andesine/labradorite in compostion). Only one core analysis was kept, the rest discarded due to significant error. It plots significantly lower than the rest of the data but more cores must be analyzed to show any true differentiation. One analysis run at the rim displayed a much lower An composition. This data point is unexplained but may be due to error during the calibration process.

FL-2A is perhaps the most interesting of the samples tested for feldspar because it shows possible signs of chemical zoning. It appears that there is differentiation between the core and rim analysis with the rims lying in the andesine-labradorite field (An_{40-60}) and the cores in the labradorite-bytownite field (An_{60-75}). The groundmass sample, although somewhat obscured by the core data, appear to lie somewhere in the middle. This apparent zoning may reflect chemical differences in the residual melt during crystallization. Specifically, the feldspar crystals may have become Na rich (Ca-depleted) during their growth. Again these grains contain almost no orthoclase.

Analyses of feldspars in ME-186 shows a very homogeneous chemical composition and virtually no differentiation between rim and core. They lie in the labradorite field (An_{60-70} and less than Or_{10}).

The next step of the data analysis involves looking at the chemical composition of pyroxene and olivine on the pyroxene quadrilateral. These graphs are plotted for each individual sample in the **appendix.** The pyroxene quad has been subdivided into compostional fields printed on the diagrams . All of the olivines tested plot on the bottom axis line between enstatite (En) and orthoferrosilite (Fe). Although these are not olivine's true end members, they can be visualized as the Mg-olivine end member (forsterite) and the Fe-olivine end member (fayalite).

All five samples contain analyses of olivine cores and rims and pyroxene grains with the exception of 106-2 which contained no significant olivine grains. Also shown on 106-2 is that there are two types of pyroxenes--augites and low Ca pigeonites. In samples ME-186, FL-2A, and 118-1, olivines plot at virtually the same spot on the En-Fe axis showing to be about 80% forsterite in composition. Olivines in 105-1 display a relatively high Fe content and are about 60% forsterite in composition.

In order to better discuss the chemical composition of pyroxenes among the samples, relative to each other, they have been plotted as pattern fields in **figure 1**. At close inspection, it is easy to see that all of the pyroxenes plot within the augite field (disregarding the pigeonites in sample no. 106-2). If these samples are in fact tholeiitic, one would expect to see an Fe-enrichment trend. These samples show virtually no Fe-enrichment trend except the slight Fe-enrichment in 106-2.

Figure 2 is a graph constructed after Miyasharo (1974) which plots the samples into two compositional fields, calc-alkaline and tholeiitic, determined by the % SiO_2 vs. FeO/MgO. Plotting the samples in this fashion reveals all of the dikes to be tholeiitic.

Fig. 1: A close-up look at the relative Fe enrichment of the samples

--pyroxenes are plotted as fields for all of the samples

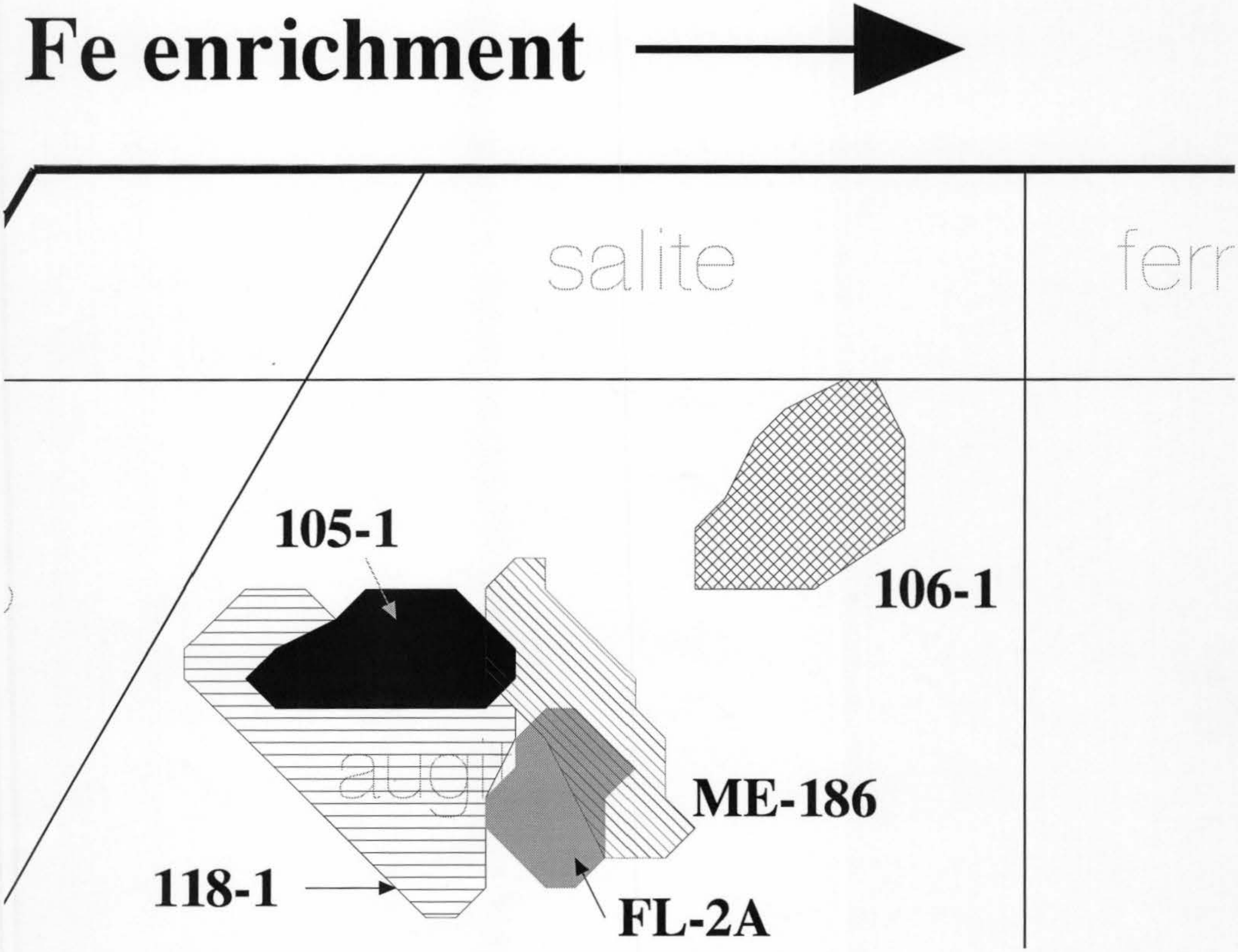
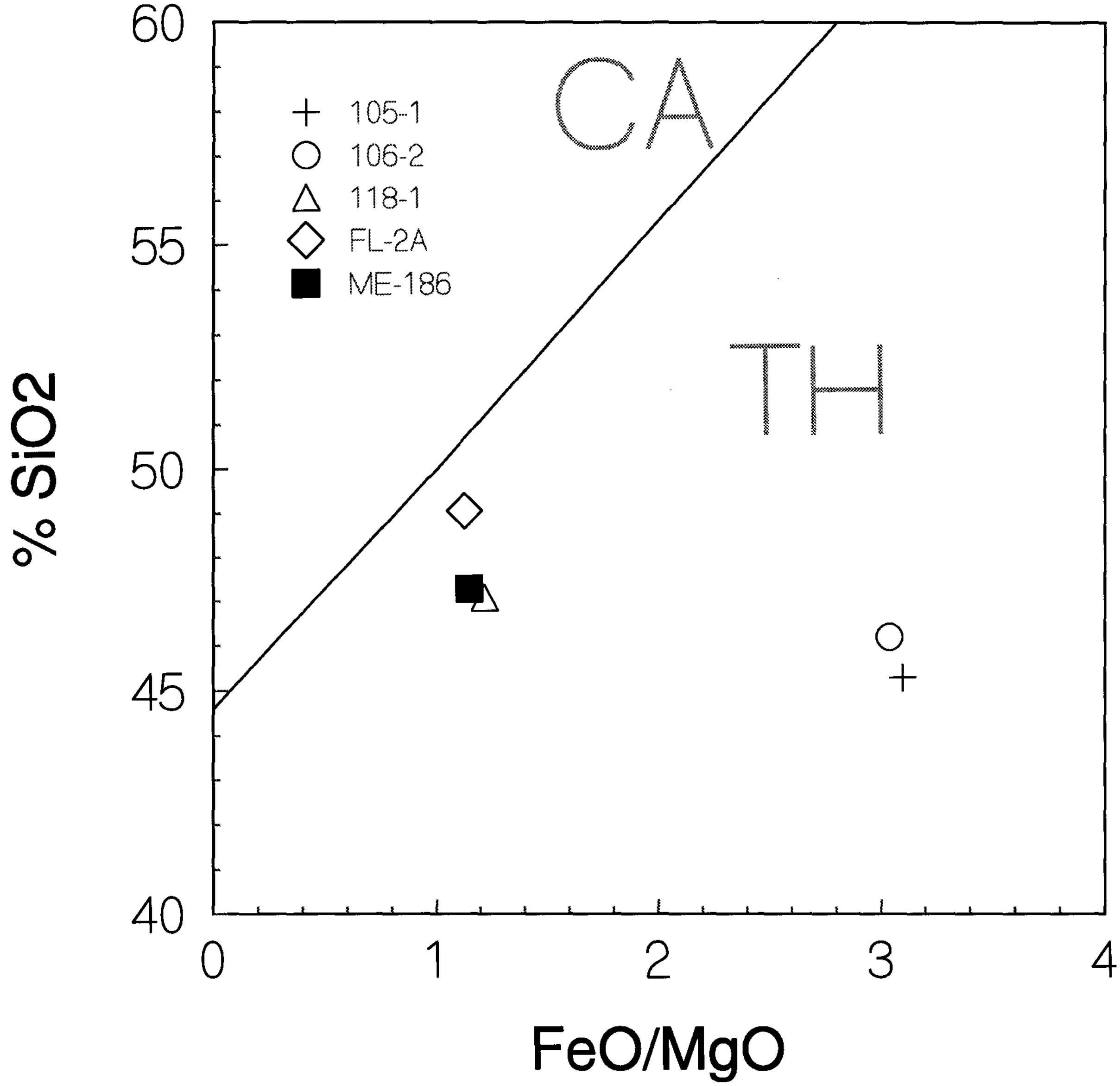


Fig. 2: Composition of the samples



CONCLUSIONS

As stated in the introduction, tholeiitic basalts typically show an Fe-enrichment trend among pyroxenes studied in a province. The five samples chosen for this study do not reveal any significant Fe-enrichment trend. Conversely, these samples plot in the tholeiitic field in the graph of SiO_2 vs. FeO/MgO. In concluding this research, it is most likely that the graph represents the most correct determination for the specific samples used in this report. The reasoning for this is that the number of analyses used is not sufficient to show this trend. Moreover, although this trend may be diagnostic of tholeiites, it is quite possible to find tholeiites without this characteristic. Taking this discrepancy into account, it can be assumed that subduction played little or no role in the genesis of these dikes. Crust that has been subducted into the mantle often contains hydrous minerals which results in magmas with high weight percentages of water. Detailed analysis of the water content in these and other samples should lead to more conclusive evidence regarding the role of subduction in the formation of the Egersund Dikes.

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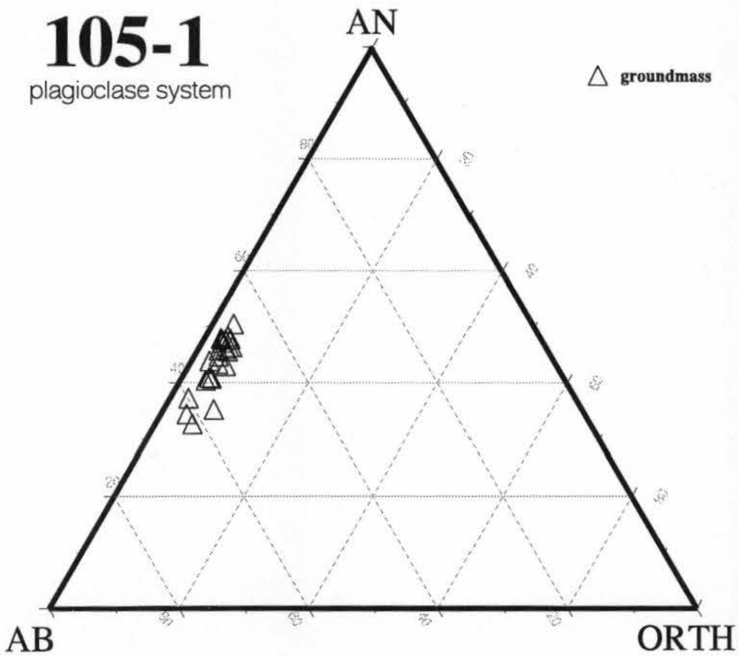
APPENDIX
(MINERAL COMPOSITION GRAPHS)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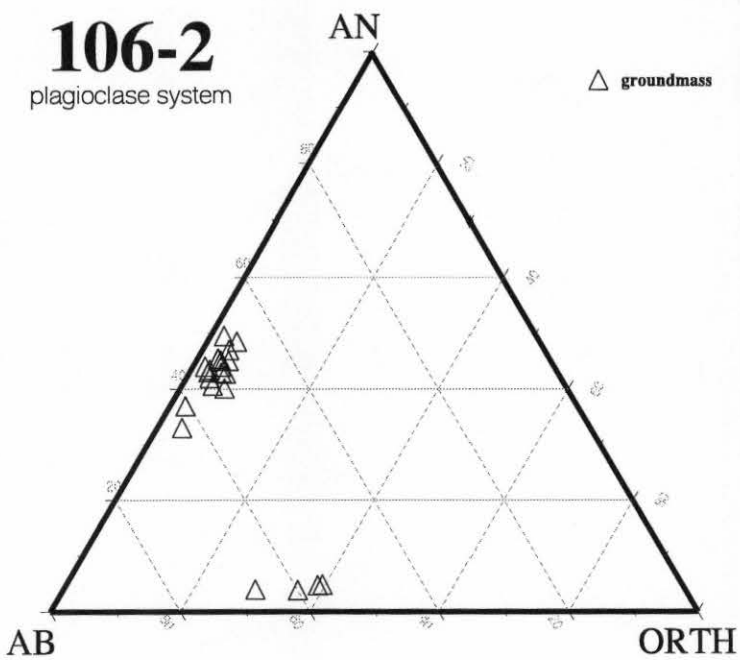
plagioclase system
AN
groundmass
AB
ORTH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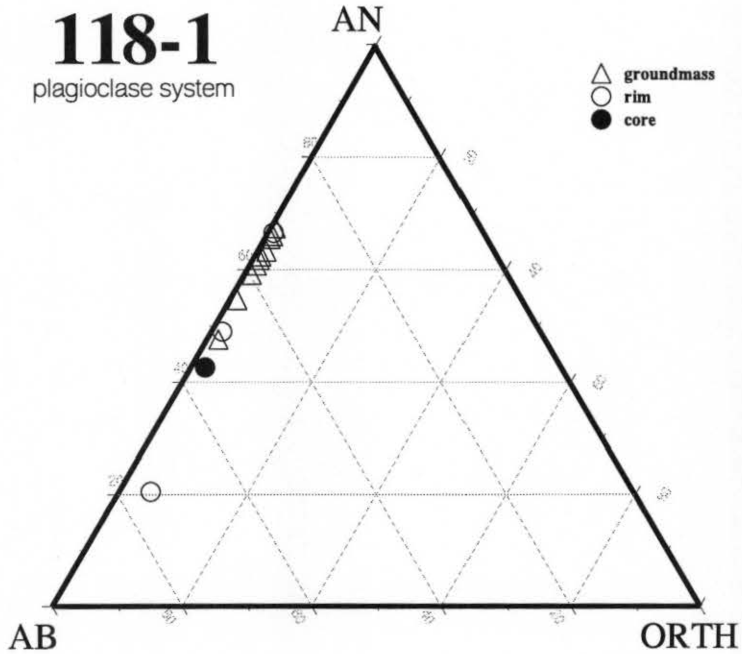
plagioclase system
AN
groundmass
AB
ORTH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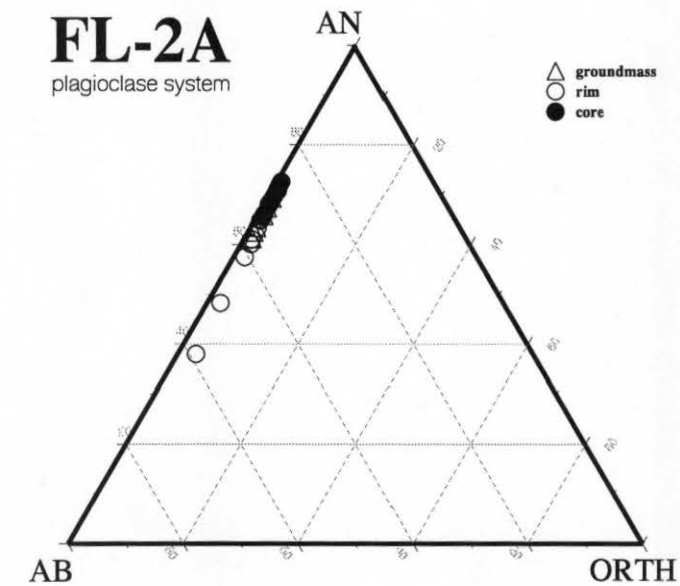
plagioclase system
AN
AB
ORTH
groundmass
rim
core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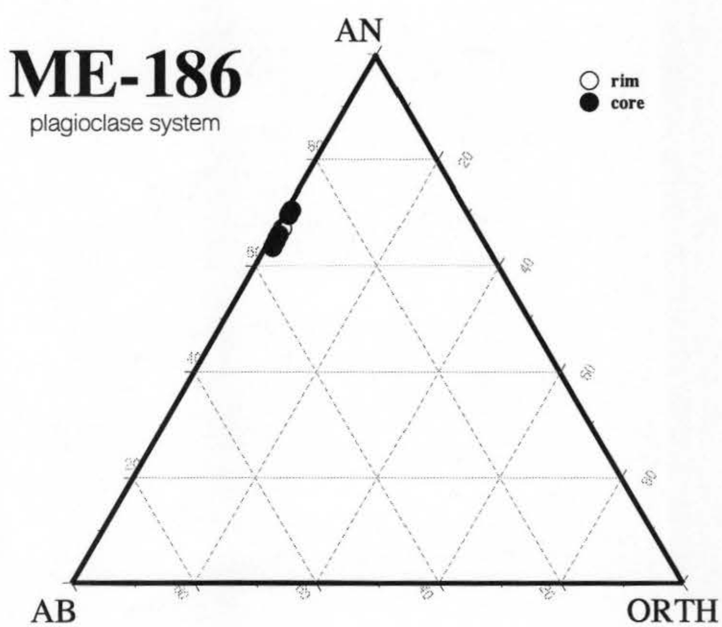
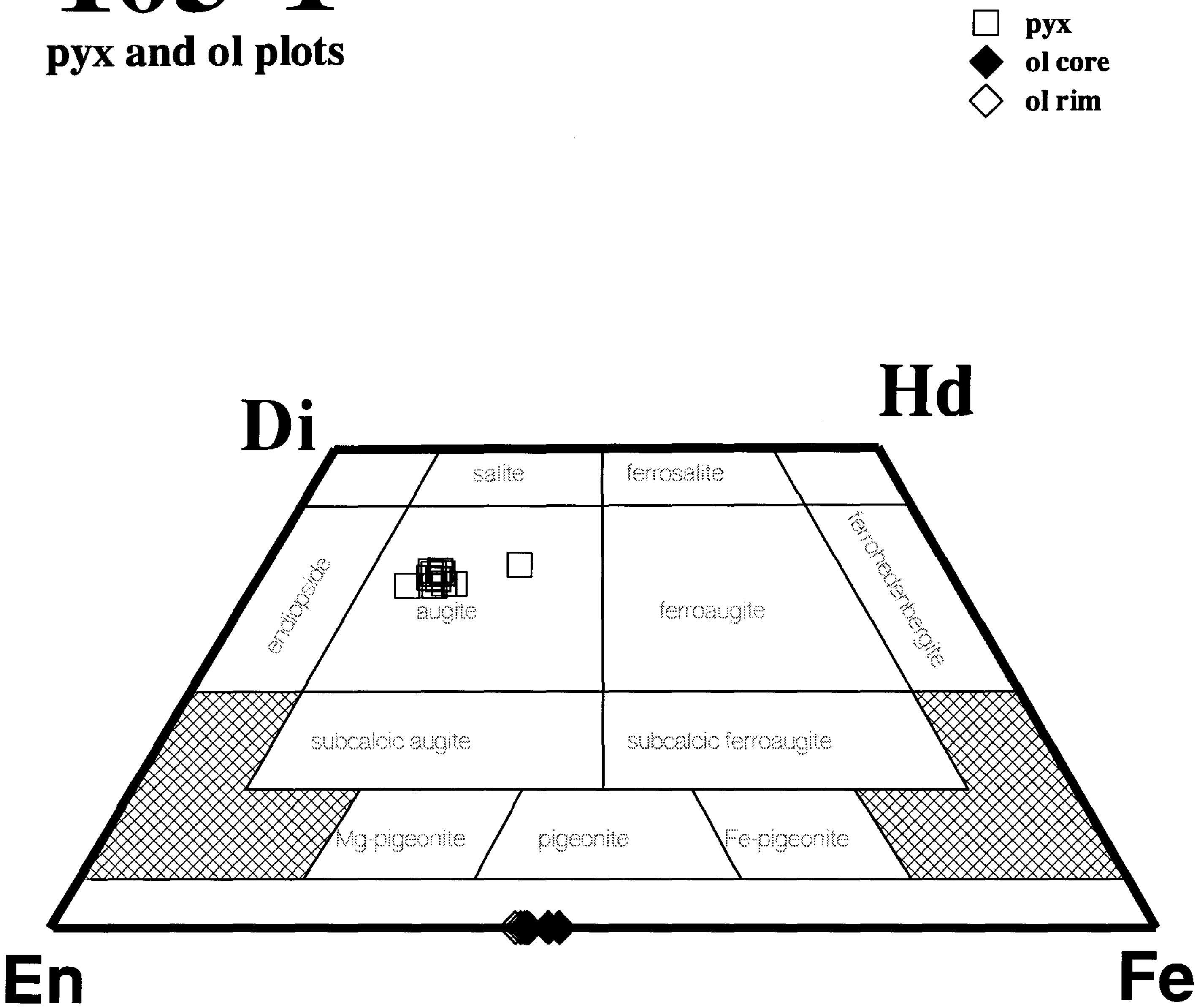
plagioclase system
AN
AB
ORTH
groundmass
rim
core


ME-186
plagioclase system
AN
AB
ORTH
rim
core

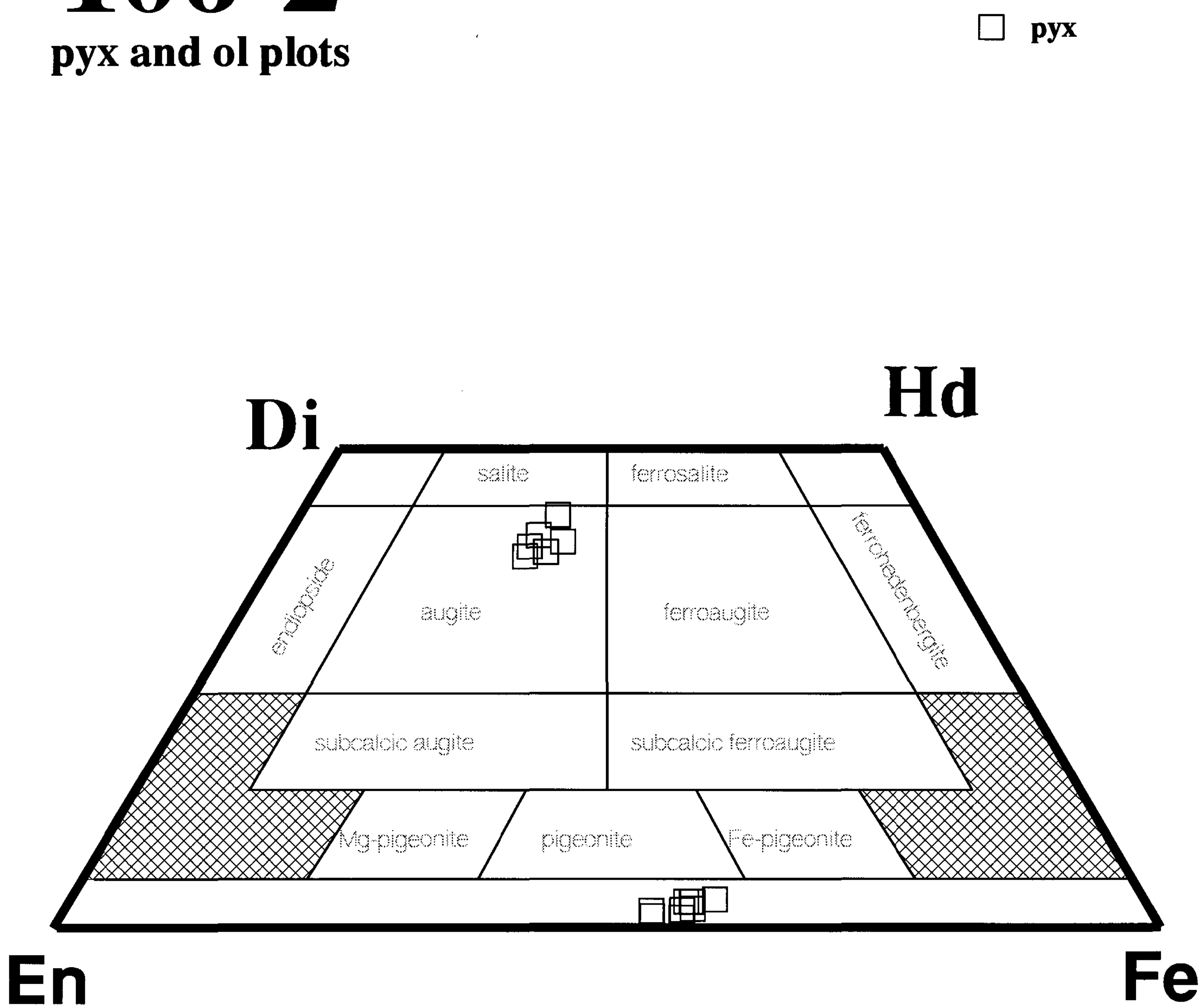
105-1

pyx and ol plots



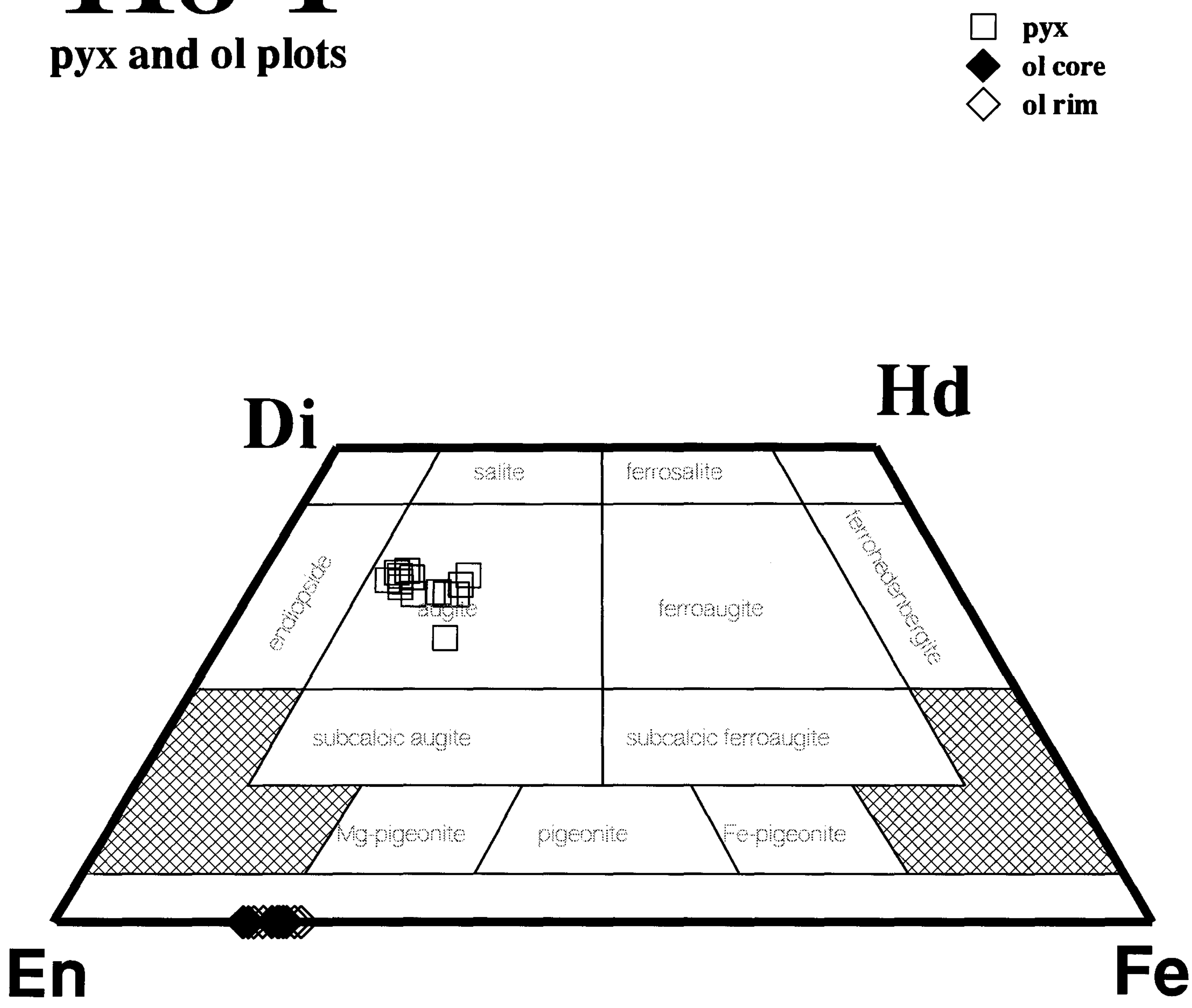
106-2

pyx and ol plots



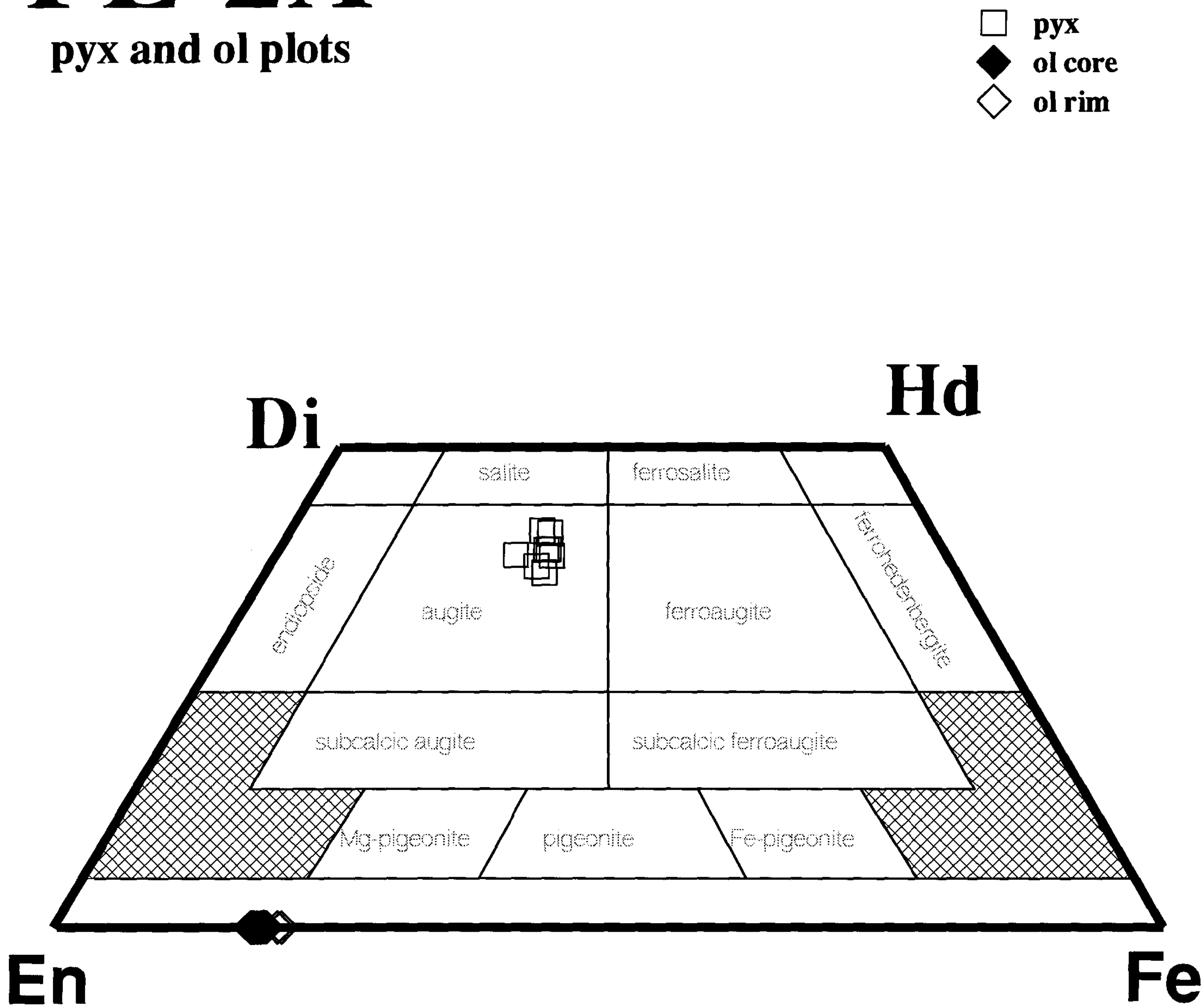
118-1

pyx and ol plots



FL-2A

pyx and ol plots



ME-186

pyx and ol plots